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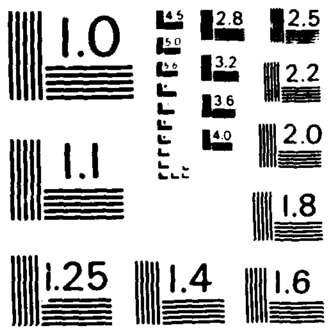

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DUST INDUCED ELECTRO-MAGNETIC NOISE (DIEMN)

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5 November 1984

Technical Report

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A review of the data and theory related to DIEMN has been conducted and a strawman hypothesis of the phenomenon proposed. This hypothesis has been used to consider the probable features of DIEMN at the MINOR SCALE high explosive event.

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SUMMARY

We have taken a quick look at the data and theory related to DIEMN and constructed a strawman hypothesis for the phenomenon. By no means do we feel that the phenomenon is understood or necessarily poses a serious threat to fielded systems; we do feel, however, that we now have a hypothesis which we can use to develop meaningful experiments and data analysis to resolve these issues.

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SECTION I
INTRODUCTION

In 1976, a high explosive event took place. The event was DICE THROW, a 600T ANFO* surface burst. The charge was in the form of a cylinder capped with a hemisphere. The detonation produced a large, dense dust cloud. At the event, Bill Graham of TRW tape-recorded the noise received by a portable AM radio tuned between stations. This tape, along with observations of lightning at the volcanic eruptions of Surtsey (1963), Heimay (1973), and Mt. St. Helens (1980), raised the concern of trans- and post-nuclear attack, dust-cloud induced communications interference.

In an attempt to gather more information on the generation of this suspected Dust Induced Electro-Magnetic Noise (DIEMN), a team from SAIC went to the 1983 DIRECT COURSE event. This team made measurements in five frequency bands (10-600kHz, 2.3-2.9MHz, 15.0-15.6MHz, 50.0-50.6MHz, 220.0-220.6MHz) beating the higher frequency bands down to 10-600kHz and recording the resulting analog signal with an EMI 600kHz bandwidth tape recorder. The intent was to measure the DIEMN in the bands of interest to BMD/BMO and to quantify the level of the noise. The result of the measurements, and complementary electrostatic measurements, was to raise more questions than answers.

In this report, we present the global physics issues involved in the DIEMN process. We begin by stating in extremely abbreviated form the available data relating to DIEMN, discuss the physical processes which must occur, relate the experimental data to our understanding of DIEMN, and conclude with recommendations for future work.

*Ammonium Nitrate (94%) and Fuel Oil (6%)

SECTION II
DIEMN-DATA IN BRIEF

The data base on DIEMN is sparse: the Bill Graham DICE THROW tape; electrostatic field-change measurements of lightning produced at the volcanic eruptions of Surtsey[1], Heimay[2], and Mt. St. Helens[3] and the observation of lightning discharges at these same eruptions; and electrostatic[4,5] and electromagnetic measurements made at DIRECT COURSE. An attempt to locate data from above-ground nuclear weapons tests that might be relevant to DIEMN is discussed in a companion report and will not be included here except to state that no hard evidence of DIEMN was found in the Weapons Test reports examined.

The DICE THROW tape made by Bill Graham was made somewhere in the AM broadcast band (500-1600kHz) with a limited bandwidth (~10kHz). This tape has "clicks" and "pops" for a time period of roughly five to ten seconds post-detonation.

During the volcanic eruptions of Surtsey in February 1964, considerable displays of lightning were seen. These lightning discharges started approximately 10 seconds after the start of each new eruption sequence. Measurements of the quasi-static electric field indicate that the clouds formed by the eruption were positively charged (as opposed to normal thunderclouds which tend to be negatively charged) and had a charge density of approximately 10-100 C/km^3.

The lightning associated with the eruption of Mt. St. Helens was reportedly spectacular in size and frequency of bolts. A compendium of eyewitness accounts[3] reports: "To some the lightning appeared to be mostly from cloud to cloud (8SE). [Note: numbers in parentheses are the approximate distance in km from the mountain in the cardinal direction given.] A heavy concentration of vertical lightning at altitudes of 25,000-30,000 ft was entirely within the vertical eruption column (40W). Others noted many cloud-to-ground strikes (9W, 15E), some of which started forest fires (12Wb) and one of which struck an individual (20N). Beneath any part of the eruptive cloud, radios became useless because of static (8SE, 12Wa, 27N). On Mount Adams, climbers noted that the air became electrically charged as the ash cloud moved overhead, and one climber received an electrical discharge upon raising his ice axe (50Ea)."

At DIRECT COURSE, electrostatic measurements were made by two groups (Naval Research Laboratory and New Mexico Institute of Mining and Technology) and electromagnetic measurements by one group (SAIC). The electrostatic measurements show a prompt positive charge followed quickly by a negative charge. The electromagnetic measurements of the SAIC team indicated that the "noise" in some of the frequency bands persisted for roughly a minute. Given the lack of knowledge of scaling relationships for this phenomena with yield, the fact that measurable charge exists as well as detectable RF "noise" is cause enough to explore the processes involved in dust charging in an attempt to put the observations in perspective.

SECTION III
BASIC THEORY

In order to produce RF noise, some form of electrical discharge is required. This implies that bulk charge has separated which in turn implies charging and charge accumulation processes exist. We propose to consider these issues sequentially from charge generation to discharge and RF radiation.

Charging Phenomena. The first process to be understood is the generation of net charge. The importance of the word "net" here must be stressed; individual pairs of oppositely charged particles exchanging charge to form neutrals can not produce substantial RF power. We see, therefore, that it is not enough to find a mechanism which produces charge exchange between interacting particles, but the mechanism must have a built in assymmetry which allows the interacting particles to separate in a preferential manner according to the sign of their charge. This is also the case in thunderstorms.

While the charge generation mechanisms in thunderstorms are not totally understood, they are generally separated into two classes: inductive and non-inductive. Inductive charging relies on the conductivity and polarizability of water and the presence of ambient electric fields to produce a top/bottom charge separation in a large droplet which becomes a free charge separation if many small droplets are continually shed from the top of the large drop. Because of the different slip velocities of the different sizes, the positive and negative drops will separate. Non-inductive charging does not require an ambient electric field, rather it depends on the presence of different materials with different surface energies or work functions. If these conditions exist, then collisions between particles of different materials will leave the materials preferentially charged. If, in addition, the materials have different sizes, then their differing slip velocities will lead to a gross charge separation.

Charge Separation. As mentioned above, in order to understand DIEMN, it is not sufficient to produce charged particles, but it is also necessary to have a mechanism for gross charge separation and charge accumulation. The simplest mechanism for charge separation is gravitation coupled with drag. The terminal velocity of a 50 micron diameter particle is of the order of 0.1m/s; that of a 500 micron diameter particle, 2.4m/s. Thus if a cloud consist of a mixture of particles with a size distribution having humps centered at 50 and 500 microns, the differently sized particles will separate with a relative velocity of about 2m/s. Given that an electromagnetic signal was received in the 50 MHz band (which implies a discharge length of the order of 6 m) this separation velocity does not seem out of line.

To form this type of size distribution in the early time ($T \lesssim 2$min) DIRECT COURSE dust cloud, it is necessary to suppose that the surface is composed of two materials with different fracture properties. However, if this assumption is made, it is relatively easy to also assume different surface energies for the materials and the charging mechanism follows directly from the argument in the previous section.

Discharge. The electric fields produced by the separated charge are the source of energy for DIEMN. The dust cloud represents a leaky capacitor (ionic atmospheric conductivity provides the leakage path). If the field surpasses the breakdown strength of the dielectric (in this case the dusty air), then a discharge can occur. This breakdown field varies from roughly 3MV/m for clean dry air at full atmospheric pressure (760 torr) to 30KV/m for air at 1 torr. It is important to understand that these breakdown strengths represent the macroscopic fields in the gap between the clean parallel plates in which these measurements were made; the breakdown field in dusty air is expected to be lower due to the field enhancement caused by the sharp dielectric points present.

The above presents the basic theoretical concepts necessary for the understanding of DIEMN. We do not intend to continue this theory discussion further here, rather we will jump to the data taken at DIRECT COURSE and quantify the theory at the same time.

SECTION IV
DIRECT COURSE

As part of our attempt to understand the DIEMN process, we took an in-depth look at the electrostatic field measurements taken at DIRECT COURSE by both the Naval Research Laboratory[4] and the New Mexico Institute of Mining and Technology.[5] The NRL system had a frequency response of 2 Hz while the NM Tech system had a response (unintegrated) of 300 kHz. The NRL probe measured the potential at 1.2 m above the surface and inferred an average E_z; this is not an easy probe to calibrate due to non-linear ground plane effects. In addition, the metal rod antenna had a large cross-section ($\sim 40\ cm^2$) which could be impacted by charged particles and thereby induce an unwanted signal. The NM Tech probes were buried and shielded somewhat but had a larger exposed sensor area ($\sim 225\ cm^2$). Also, the probe was based on the detection of fringing field inside an open box with a normal electric field applied to the open face; this is also a very difficult probe geometry to calibrate.

The calibration factor for the NRL probe was ~ 1 kV/V and it therefore saturated at a field of ~ 10 kV/m; the NM Tech probe had a calibration factor of $\sim 300\ kVm^{-1}/V$ and a saturation value of 56.3 kV/m. In addition, the NM Tech crew ascertained that 0.6 nC ($4 \times 10^9 e$) incident on the sensor will by itself saturate the detector. The NRL team did not determine the equivalent sensitivity for their detector.

Figure 1 gives a crude indication of the test site and the locations of the dusty radial and the NRL and NM Tech detector locations.

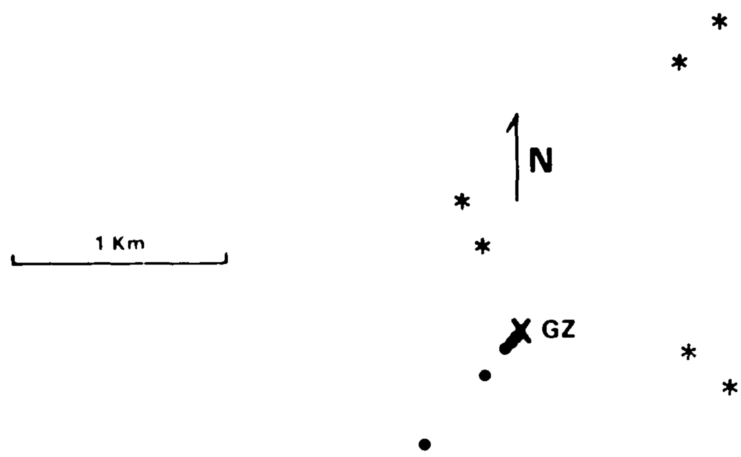

Figure 1. Location of NRL (*) and NM tech (•) sensors.

The maximum recorded field strength for each team was 1700 V/m (T + 72 sec, 1225 m from GZ) by NRL and a saturation field of 56300 V/m (T + 4 sec, 120 m from GZ) by NM Tech. (All numbers quoted are approximate). In order to get a little better feel for the (lack of) correlation between the two data sets, it is instructive to look at the NRL data for a station 2285 m from GZ and the NM Tech data at 1975 m. The NRL measurement peaks at T + 53 sec at a value of 350 V/m; the NM Tech peak occurs at T + 5 sec with a value of 12000 V/m. Obviously, based on these last results, the data of the two groups do not correlate at all.

The NM Tech researchers realized the lack of correlation in their own data at different stations and reported such at the January, 1984 DIRECT COURSE workshop held at NRL: "There is little correlation between the electric field disturbances observed at adjacent sites (which indicates that the charges affecting each sensor were close to it)." This explanation applies only to data taken post-shock; pre-shock, no local disturbances (and hence local charge separation) can take place. Therefore, the early time (pre-shock) NRL data should not be affected by local changes.

Figure 2 shows the NRL pre-shock data. The peak occures at approximately T + 0.6 seconds; at this time the shock radius is 375 m and the closest data station is 1225 m. Since the spatial dependence of a dipole is R^{-3} and that of a quadrupole is R^{-5}, the quadropole moment effect should be an order of magnitude less at the <u>nearest</u> recording station and we should be able to consider the problem to be that of a dipole.

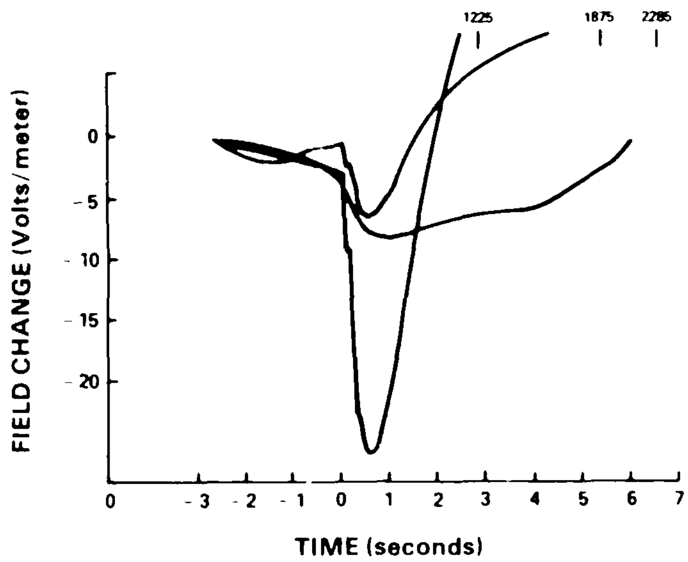

Figure 2. NRL pre-shock data (arrows denote shock arrival).

Given a charge Q a distance d above conducting plane, the vertical electric field at the conducting plane is given by

$$E_z = \frac{2Qd}{(r^2+d^2)^{3/2}} \tag{1}$$

Two measurements of the field suffice to determine Q and d. The NRL data at T + 0.6 sec is:

Data Point	r(m)	E_z(V/m)
1	1225	26.2
2	1875	8.0
3	2285	6.6

The following pairs result in the given values of dipole charge and height:

Data Pair	Q(mC)	d(m)
1-2	8	405
1-3	6	980
2-3	6	2945

Thus we see that the dipole height (which must be less than the tower height - 50 m - plus the shock radius - 375 m - or 425 m) varies from the physical to the grossly unphysical, calling the data and its interpretation into question. What is the mechanism for producing these charges and fields in only 0.6 sec? Part of the problem may be that the NRL probes had a frequency response of 2Hz; nevertheless, serious questions are raised.

This electrostatic data represents the problem we face throughout the analysis of DIEMN--the data is tantalizing in the sense that it exists, but upon closer inspection lacks high confidence. The electromagnetic data suffers the same fate. Figure 3 shows the relative magnitude of the DIEMN signal above background in a 10 kHz bandwidth. Two things must be noted: 1) the data is ambiguous and 2) there are only 10 (non-prompt) events observed. The ambiguity means that no single event may be relied upon absolutely; the total of 10 events is too few for statistical analysis. In addition, the small number of events introduces the issue of the causal relationship between the DIRECT COURSE event and the measurements; specifically would the noise observed have been there even without the shot. This last issue cannot be ignored since virtually no pre-shot data was recorded.

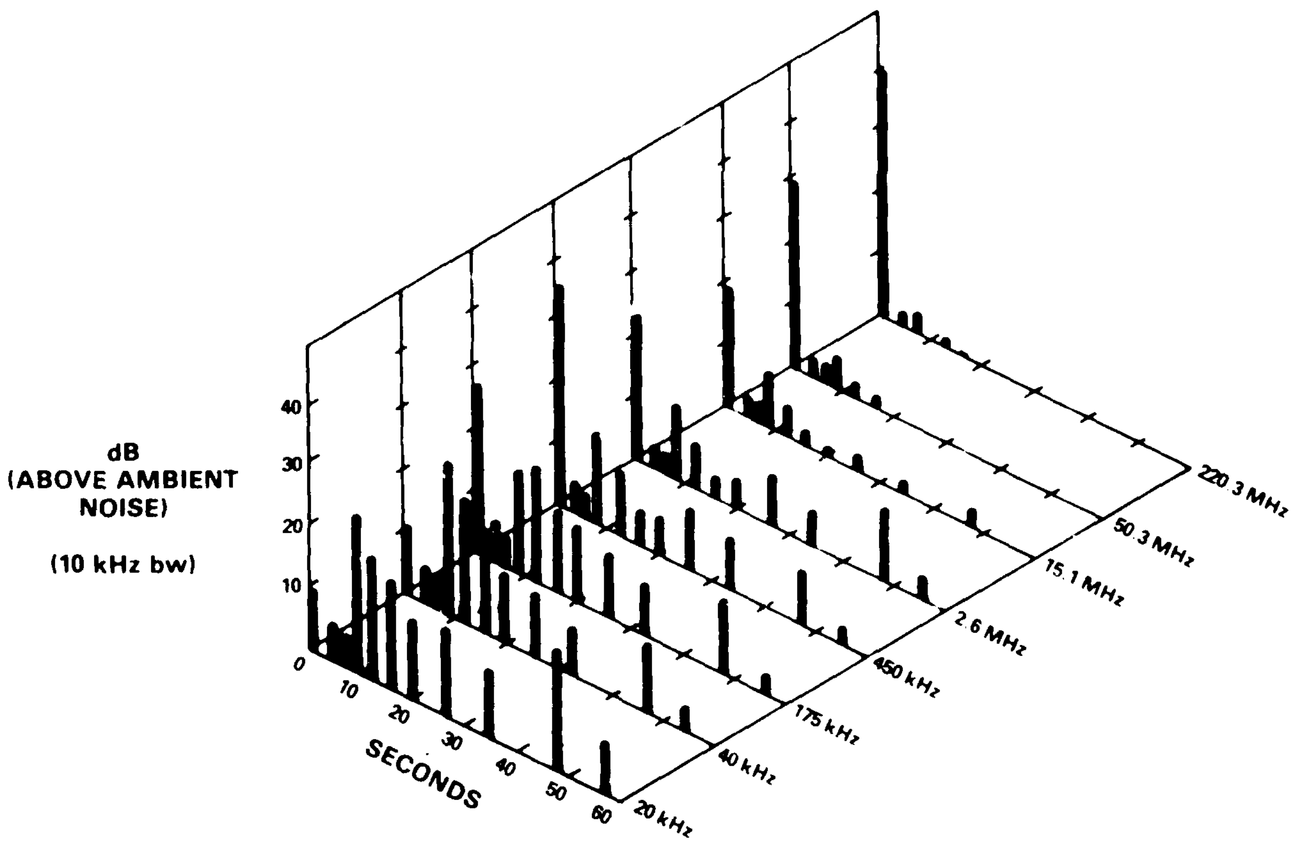

Figure 3. SAIC prompt and delayed noise data.

SECTION V
RECOMMENDATIONS FOR FUTURE WORK

The issue of DIEMN contains numerous open issues. The charge production mechanism has not been positively identified, nor the separation process. The breakdown strength of dusty air is unknown and the basic breakdown process is still open for questions. The amount of charge created and the conversion efficiency into RF radiation in the frequency bands of interest is unknown.

The only way for progress to be made in this effort is to form an hypothesis. A working hypothesis can be used to make predictions which can be subjected to experimental verification. Without some starting point, the number of questions becomes insurmountable.

To allow us to formulate a working hypothesis we begin by listing what we feel we know with some confidence: 1) there are free charges (as seen by both NRL and NM Tech) and 2) there are discharges (as indicated by the DICE THROW, Mt. St. Helens, and DIRECT COURSE observations). Based on this information, we consider it valid to propose a strawman hypothesis for DIEMN.

The hypothesis consists of a charging mechanism based on contact electrification between two different component materials of the dust which have different size distributions and which therefore separate due to their different slip velocities. This is a hydrodynamically driven process and therefore, if we assume that we are far from saturating the charge on the dielectric, the charging process must scale by $(\text{Yield})^{1/3}$. The discharge, on the other hand, is governed by the properties of the dusty air (e.g., breakdown strength, conductivity) which should be relatively insensitive to yield; thus an increase in free charge should result in more discharges, not longer discharges. The result is that the amplitude of the noise signal is unlikely to increase much with yield, however the duration of the noise will increase.

To investigate this strawman hypothesis, we recommend that: (1) A repeat of the DIRECT COURSE electromagnetic measurements be made at MINOR SCALE to investigate the yield dependence on the amplitude and duration of the noise; and (2) that a laboratory experiment be conducted to determine the breakdown characteristics of dusty air. We do not believe that a repeat of the electrostatic measurements is warranted due to the problems of calibration and contamination of the signal by charged particles striking the detectors.

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Sperry Corp
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Sperry Corp
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